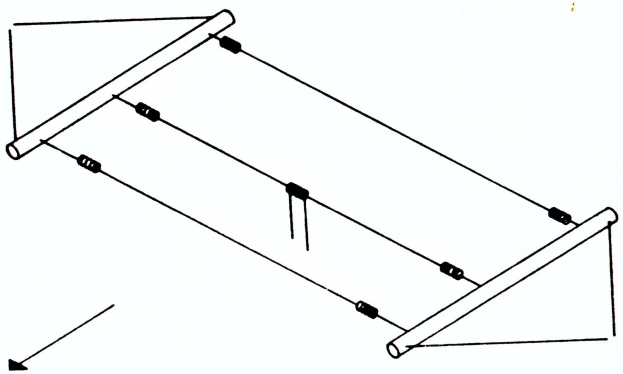


fig.21

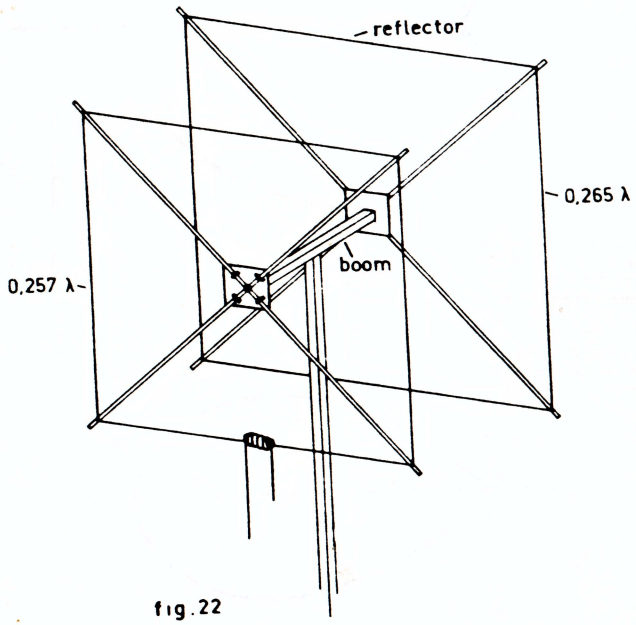


fig.22

RADIO NEDERLAND
WERELDOMROEP

THE DUTCH INTERNATIONAL SERVICE
P.O. Box 222-1200 JG Hilversum-Holland

SHORTWAVE ANTENNA COURSE

by
Jim Vastenhoud

INTRODUCTION

In the early days radio receivers had to be equipped with big antennas for the satisfactory reception of at least a few stations. When the electronic circuits in receivers became more sensitive, external antennas became less important. By the end of the 1940's there were experts who suggested that there was no need at all to install these antennas, because the sets had built-in ferrite antennas which were supposed to guarantee a good reception. However, this turned out to be rather too optimistic a view. For the arrival of FM changed the face of radio, not only because of the added range of frequencies on the dial, but also because of the appearance of the "telescope" or "whip" antenna, a short rod extending vertically from the receiver.

The ferrite and the (short) telescopic antenna, however, are neither of them perfectly suitable for the reception of shortwave transmissions. The ferrite becomes less effective on the shorter wavelengths, and the rod antenna is too short to be really effective, in particular when the receiver is operated inside a building which partially absorbs the signal, or when the steel reinforcement rods used in the structure of the building prevent the signal from reaching the receiver. Therefore, the use of an outdoor antenna is always to be recommended for shortwave reception, and especially for international shortwave reception.

An antenna converts the incoming "wave" into a small electric voltage which is then fed into the antenna input of your radio. A proper antenna will allow you to make better use of your radio.

This course deals in particular with shortwave antennas. Some of them are of the "general" type, which perform equally well on other wavebands, for instance, the medium wave. Others are more "selective" and will give a superior performance on shortwave, while being less "sensitive" on other wavebands.

Before discussing the various types of antennas and their construction, we will give you a few definitions and some theory which will come in handy at a later stage. If this should give you the feeling that it is all a bit too complex or time consuming, there is an alternative: you can ask us to send you our antenna booklet, which is also free of charge. It gives you general and practical information about several antennas of the general type.

Many shortwave listeners are very much interested in antennas, because they are cheap and easy to construct, and will substantially enhance the reception capacity on shortwave. So we have tried to make this Shortwave Antenna Course interesting as well as useful.

The figures illustrating this course were designed and drawn by Wim van Amstel. They will, no doubt, make it easier for you to understand the text. Wim was also responsible for the lay out.

Hilversum, November 1981

Jim Vastenhoud
RADIO NEDERLAND

LESSON 1: General information and definitions

Antennas are used for transmission and for reception. To describe the properties of antennas, engineers had to find the right terms and definitions. They decided to base these terms and definitions on the transmitting antenna. This means that some of the terms used in this course are seemingly referring to transmitting antennas, while we are only dealing with receiving antennas. That is because they are basically the same. The only difference is that transmitting antennas need a power handling capacity, which receiving antennas do not need.

The transmitting antenna is connected to the output circuit of the transmitter. It "converts" the high-frequency power generated in the transmitter into electromagnetic radiation. This radiation propagates in space as a combination of an electric and magnetic wavefield, and travels at the speed of light (approximately 300,000 km/sec) from the transmitting to the receiving antenna.

Some antennas are more effective than others. The effectiveness can be expressed by defining the amount of transmitter energy which is converted into radiation. This property of the antenna is its radiation resistance. The higher the radiation resistance, the higher the part of the total transmitter energy which is converted into high frequency radiation, and thus radiated into space.

If this radiation is equally strong in all directions, the antenna is called an isotropic antenna. The isotropic antenna is used as a reference for all antenna types. Since most antennas are more or less directive, in which case more radiation is released in one (or some) direction(s) than in others, one needs a way to express the signal gain of the maximum radiation, with respect to the isotropic radiator. This signal gain, or simply "gain", is always expressed in decibels. The decibel is a scientific unit of comparison between two similar powers. A power of 100 kilowatt, for instance, is 100 times stronger than a power of 1 kilowatt. In the decibel language, the ratio between the two is 20 decibels (abbreviated: 20 dB).

The decibel is also used as a means to express voltage and current ratios, provided that they run through equal resistors. In this case, 100 volts is 40 dB with respect to 1 volt (measured over an identical resistor).

If you are interested in more details, the definitions are:

-to express power ratios: the number of dB's = $10 \log_{10} \frac{P_1}{P_2}$

-and to express voltage or current ratios: the number of dB's = $20 \log_{10} \frac{V_1}{V_2}$

The following table shows the various ratios and the relative values in decibels:

dB	power ratio	voltage or current ratio
1	1.26	1.12
2	1.58	1.26
3	2.00	1.41
5	3.16	1.78
7	5.00	2.24
10	10.00	3.16
12	15.85	3.98
15	31.62	5.62
20	100.00	10.00
30	1000.00	31.62

Decibels are generally used to express the antenna gain towards maximum radiation, with respect to the isotropic antenna. The "gain" of a dipole antenna is 2.16dB. Some highly directional shortwave transmitting antennas boast gains of 18 to 22 dB.

- 0 -

LESSON 2: More antenna properties and their names

The radiation characteristics of an antenna are usually expressed by two graphs. They are called: radiation patterns.

In the first lesson, we learned that most antennas do not radiate an equal amount of signal in every direction, but show directivity. This directivity will usually vary with the wavelength. So if the antenna receives on a different waveband, its sensitivity for signals from various directions will differ from the sensitivity on the original band. The details on sensitivity are usually expressed in a diagram, which applies when the antenna is tuned to one particular frequency, the so-called resonant frequency of the antenna. This is called a radiation pattern, or polar diagram. It can be shaped like a cigar, pear, doughnut or melon. Usually two diagrams will suffice to characterize the main radiation properties of the antenna: the vertical radiation pattern and the horizontal radiation pattern. The vertical pattern gives a side view of the radiation cones, and the horizontal pattern a plan view. See figure 1.

The main radiation lobe, or main lobe, is represented by the biggest cone in each of the patterns. The longest arrow in the vertical radiation pattern makes an angle with the horizontal plane, which is called the elevation angle of the main beam. In amateur antennas it can be 30 to 60 degrees. Professional antennas for long-distance coverage can have elevation angles of 7 to 12 degrees. In our example, the horizontal pattern shows that the bulk of the radiation goes one way. See Figure 2.

Here we need a definition to express the beamwidth of the antenna. This beamwidth is chosen to be the angular distance between the directions at which the (transmitted) power is one-half the maximum power. In most diagrams, this point lies at 0.71 times the vector for maximum fieldstrength. Directional amateur antennas have horizontal beamwidths of 40 to 80 degrees, and professional shortwave antenna arrays can narrow their beam down to approximately 25 degrees.

In shortwave broadcasting, wavelengths between 11 and 50 metres are in common use. Since the antenna efficiency increases when its actual length shows a harmonic relationship with the received wavelength, all "better than average" shortwave antennas are so-called tuned antennas. Usually, they are half a wavelength long. A standard type is the half-wave dipole antenna.

Since the symbol for "wavelength" is λ (lambda), such antennas are referred to as $\frac{1}{2}\lambda$ antennas. Also in existence are full-wave (λ) antennas, and $\frac{1}{4}\lambda$ (quarter-wave) antennas. Antenna lengths of less than a quarter wave are called small antennas. Antenna lengths can also be indicated in electrical degrees. Since one full cycle is 360 degrees (360°), a half-wave dipole is 180 degrees, etc.

The expression of antenna dimensions in wavelengths is, however, the more familiar. It is also highly appropriate, since the dimensions of tuned antennas depend on the wavelength to which they are cut.

- 0 -

LESSON 3: Dipoles

The shortest tuned antenna is the half-wave antenna. Its proper name is "resonant" antenna, because the antenna has a length which acts as a resonant circuit when it is half a wavelength long. Resonant circuits are well known in radio engineering as combinations of coils and capacitors, which cause a signal gain at certain frequencies. The same applies to resonant antennas.

The standard half-wave (resonant) antenna is the half-wave dipole. It consists of two straight wire (or: rod) sections, each one quarter wave long, and positioned in one line (collinear). See figure 3.

The antenna is usually fed in the centre. Its radiation resistance is about 73 ohms, but varies with the height of the antenna above the ground.

The horizontal dipole has a characteristic, 8-shaped, horizontal radiation pattern. Its maximum radiation is in the directions perpendicular to the antenna axis, and its minimum radiation (or: null) lies in the directions of the wire axis. See figure 4.

Its vertical radiation pattern varies with the height of the wire above the ground, as shown in figure 5 by a number of diagrams. At a height of 0.2 wavelength (λ), its radiation is mainly upwards, but the elevation angle is reduced when the antenna is positioned higher above the ground. For nearby SW listening, 0.25 or 0.3 λ seems appropriate, but for distant SW reception the antenna must preferably be at 0.4 or 0.5 λ above the terrain.

Above 0.5 λ, one notices the appearance of a small extra lobe, pointing straight upwards. This lobe increases if the antenna is positioned even higher, so this does not seem practical.

As indicated earlier, the radiation resistance of the antenna also fluctuates with its height above the ground. The following table illustrates this:

height above ground	radiation resistance (ohms)
1/8 λ	36
1/4 λ	78
3/8 λ	96
1/2 λ	75
5/8 λ	59
3/4 λ	78
7/8 λ	83
1 λ	73

It is worth noticing the various impedances, as they will turn out to be important when it comes to hooking up a feeder line to the antenna, in order to connect it to the receiver.

The dipole antenna is available in many different shapes, and some of them have definite functions which enhance the desirable properties of this antenna type. One of these is the bandwidth of the antenna. Since the dipole is a resonant antenna, it will only give a superior reception over a limited range of frequencies, coinciding with its bandwidth. Beyond that range, its performance will drop off to normal values.

For a (relatively) thin wire (e.g. 1 mm), the bandwidth of the dipole is limited to about 2% of the frequency to which it is tuned. This will amount to one shortwave broadcasting band, if the resonance frequency is chosen at mid-band. To increase the bandwidth, the common method is to increase the wire diameter of each antenna limb.

Since the antenna would become very heavy and expensive if we were to apply solid tube, the practical way is to prepare cages of antenna wire, as illustrated in figure 14.

The dipole with the equal-diameter cages is called a cage-dipole, and the one with the cone-shaped limbs is called a biconical dipole. In a later lesson, when it comes to the practical realisation of antennas, we will discuss practical sizes for these kinds of dipoles.

- 0 -

LESSON 4: Vertical antennas

Out of the half-wave dipole, many antenna types have been developed, and the best known of these is the quarter-wave antenna, which has an actual length of about one quarter wavelength.

Well known are the transmission towers of medium wave stations. Many of these have a length of one quarter wavelength (half-wave towers also exist). Such a tower sits on a ceramic ball, to insulate it electrically from "ground". From under this mast insulator, a number of copper wires will run in many different directions. Each of these "radials" is again one quarter wave long, and is buried in the ground at a shallow depth. It is called the "ground system".

With a little bit of imagination, one can consider this combination of vertical tower and "radials" as an upright dipole antenna, with half of it buried in the ground. This buried half-dipole is represented by the ground system of hundreds of radials fanning out from underneath the tower insulator.

The quarter-wave antenna, installed as described, has a radiation resistance which is half that of the dipole, so it is 36 ohms. The diagram of this antenna type was represented in figure 1, lesson 2. It is doughnut-shaped. The sensitivity of signals arriving from a horizontal direction is the same for all directions. Vertical antennas are considered to be omni directional. The vertical radiation pattern, however, shows that the elevation angle is in the order of zero degrees, and the sensitivity drops off rather quickly if signals arrive at angles of 30 degrees or more with the horizon.

The quarter-wave rod antenna is also popular in shortwave, especially with those who have only a limited space at their disposal. Since a quarter wave of e.g., the 19 metre band is less than 5 metres, shortwave verticals have practical sizes and can be executed as "whips" or "rod antennas" placed on top of a house. The radials, however, must not be forgotten, because they give the antenna its superior performance at resonance. Such a quarter-wave rod, with a set of four radials (each ¼ λ long) fanning out from underneath its feedpoint, is called a ground plane antenna (fig. 6).

Quarter-wave antennas, operating on the shortwave band, can be made more versatile by making them tunable to various wavebands. This is possible by adding passive electronic components in the right places, e.g. at the feedpoint of the antenna. We will explain this in more detail.

The quarter-wave antenna is only resonant for one waveband. For the other bands, it is either too long (for shorter wavelengths, or higher frequencies), or too short (for longer wavelengths). To make the antenna resonant for a longer wavelength, we must either add capacity at its top, or inductance at its feedpoint. To make the antenna electrically shorter, we must add capacitance at its feedpoint. This is illustrated in the various figures given.

Top capacity is very easy to realise. Just connect the top of the antenna to a metal plate, or a horizontal wire, or a couple of wires. What you then get is a so-called L-antenna, also called "wire antenna". See figure 7. It is the universal, easy to install antenna, because top capacity and vertical "rod" can be made out of one piece of wire, to form the complete antenna.

If we want to "tune" this antenna to a band for which it is electrically "long", we can put a variable capacitor between the antenna and the receiver. This is a "shortening capacitor". The second indicated method to increase the "electrical" length, without enlarging the mechanical size, is to add a coil at the feedpoint of the antenna. Such a coil is usually named a "loading coil". For specific bands, the coil must have a certain number of turns. However, if we use the antenna for different bands, we can make the inductance variable by tapping the coil at various windings, and shortcircuiting some of them, with the help of a multi-position switch.

Finally, it seems appropriate to combine the shortening capacitor and the loading coil (with taps) into a so-called tuning unit, which enables us to make the antenna resonant for a number of wavebands. This is also illustrated in figure 17. Practical data will be supplied later in the course.

- 0 -

LESSON 5: The "folded" dipole antenna and the loop antenna

Two more antenna types can be considered significant variations on the single dipole antenna, as they operate on the same basic principles. The first one is the so-called folded dipole. It is a half-wave dipole, with a second conductor, also a half wavelength long and of equal diameter, strung parallel at a small distance. This parallel wire is connected to the extreme ends of the single dipole, which thus forms a closed loop, with a total conductor length of a full wavelength. This is shown in figure 8.

The folded dipole has some properties which make it preferable to the single dipole in a number of cases. Its radiation resistance is 4 times as high as that of the single dipole, and is about 300 ohms. This makes it perfectly suitable to operate in conjunction with a 300 ohm balanced feeder line, which is a well known type in use for television antennas. The folded dipole is also the heart of many television antenna systems, but, in these cases, it is usually made of tubing instead of (copper) wire. The fact that the radiation resistance of the antenna and the feeder line "impedance" are the same, indicates that the electric signal which is available at the antenna terminals, can be transferred (almost) lossfree to the feeder line, which, in turn, will deliver the signal at the antenna input terminals of the receiver.

Another positive property of the folded dipole is that it has a wider banwidth than the single dipole, even if the two wires are thin. The terminal resistance of the folded dipole, which is about the same as the radiation resistance at resonance, is usually called the feedpoint impedance. The term "impedance" seems difficult, but indicates only the resistance at radio frequencies. In electrical engineering, the word "resistance" is only valid for DC (direct current), which is the type of electricity which is generated by a dry battery or delivered by a car battery. For all AC (alternating current) applications, the term is "impedance".

The feedpoint impedance of the folded dipole can be varied (and so, adapted to your needs) in various ways, e.g., by the application of a different wire diameter for the parallel wire. More details will be given in a following lesson.

Related to the folded dipole antenna is the single-turn loop antenna. Loop antennas can be classified in two categories: small loops and large loops. A small loop has a total conductor length which is small with respect to the wavelength, and is not interesting for our purpose.

The smallest "large" loop is the half-wave loop, but the one we like to deal with first, is the full-wave loop. (See figure 9). Its total conductor (wire) length is one wavelength, and it is arranged in the form of a square, with sides of one quarter wavelength. As you will notice immediately, there is a relationship between this antenna and the folded dipole, which is also a closed full-wave loop, but arranged like a strip rather than a loop.

There are also similarities in radiation properties. The radiation maximum of the full-wave loop is perpendicular to the plane of the loop (like the dipole), and minimal in the plane of the loop. The radiation resistance is about 100 ohms, which is above that of the single dipole but below that of the folded dipole.

In radio amateur circles, arrangements of loop antennas are known as "quad antennas" or "quad arrays, and they are rather popular in some countries, because they are light, easy to construct; they can be made rotatable and can reach substantial gains. in a later lesson, we will deal with the practical details of the "quad".

The half-wave loop has limbs of 1/8th wavelength, so that its total conductor length is about half a wavelength. Again, the wires are arranged in the form of a square, and the feedpoint is usually chosen halfway one side.

The properties of the half-wave loop differ from those of the full-wave loop. The maximum radiation is now in the plane of the antenna, and away from the feedpoint. The sensitivity in this "forward" direction is better than that in the "backward" direction. In technical terms, the antenna has a "front-to-back ratio" of about 4 dB.

The feedpoint impedance of this symmetrical antenna is about 50 ohms. The half-wave loop is less sensitive than the full-wave loop, but the difference is marginal: about 1 decibel.

- 0 -

LESSON 6: Transmission lines (I)

In most cases, the antenna is not directly coupled to the receiver (or the transmitter), because the antenna is outdoors, as free-standing as possible, while the transmitter or the receiver is inside. The wire (or wires) which carries the signal between them, is called the "transmission line", or "feeder line", or simply "feeder". The feeder can be the source of a considerable signal loss, if it is wrongly applied. Let us explain this in a bit more detail.

If a transmitter feeds its signal to the transmission line, it travels down the line to the antenna. If the "matching" between the two is correct, the signals are absorbed by the antenna and radiated. If the matching is not correct, waves are reflected and return to the transmitter. In fact, the reflected energy is lost. Since both the incident and the reflected wave are of equal frequency, the resultant wave (at any moment) seems stationary, although both incident and reflected waves are moving. This effect of the stationary, or standing waves, gives an indication of the signal loss in the feeder, caused by an improper signal transfer from transmitter to feeder, or from feeder to antenna. Generally, one speaks of mismatch. If the mismatch is large, a lot of signal is lost by reflection, and the standing wave ratio is large. If the match is correct, the standing wave ratio (SWR) is near unity. Matching is correct when the transmission line is terminated with an impedance which equals its own, "natural" impedance.

The "natural" or "characteristic" impedance is ohmic and appears when a signal is connected to an infinitely long line. Due to the distribution of electrical properties along such a line, like the capacitance between the wires and the inductance along them, there is one specific value at which these cancel each other out and result in an ohmic resistance, which has received the name "characteristic impedance". There is quite some standardization in cable impedances. Well known are the 50 ohms and 75 ohms coaxil lines, and the 300 ohm symmetrical (parallel) feeder.

It is important to try to arrive at correct matching in your antenna system, by using the type of feeder which is closest to the antenna input impedance of the receiver, and to adapt the antenna radiation resistance to this value. If a commercially available feeder line does not match your receiver and antenna impedances, you must find a way to match them, e.g., by using a home-made transmission line of the correct characteristic impedance, or by using an impedance transformer.

Electronic signals travel with the speed of light (300,000 km/sec) in a vacuum, and at a slightly lower velocity in the atmosphere. Along a wire, or in an electronic circuit, the transmission speed can be much slower. In cables, the speed of propagation of the signal is sometimes important, especially where matching problems are concerned. That is why, for all types of cable used in radio transmission, the velocity factor is given. Because the velocity of propagation is lower in cables than in free space, the electrical length of an antenna, or a wave-related piece of feeder line, is larger than the physical (real) length. The velocity factor, or shortening factor, multiplied by the electrical length, gives the mechanical length. For a parallel, open wire transmission line, the velocity factor is close to unity (0.95 - 0.97). For a solid-dielectric twin line, like a twin lead, or a tubular, teflon-insulated twin line, the velocity factor will be around 0.82.

In coaxial lines, the velocity factor also varies with different insulation materials. An air-insulated coaxial line has a velocity factor of around 0.85, and solid-dielectric coaxial line shows a velocity factor of 0.66.

Another property of transmission lines is that there is an increasing signal loss if the frequency is increased. The attenuation is small for parallel lines, and larger for coaxial lines. It varies with the dimensions of the line and the wire sizes applied.

For HF-frequencies, the attenuation is relatively small, usually from around 0.2 dB per 100 feet (30 metres) at 6 MHz to 0.5 dB per 30 metres at 21 MHz. These values refer to parallel lines. Coaxial lines range, for similar frequencies, from around 0.5 to 1.5 dB per 30 metres. If you need a long transmission line, it is worth while to consider these data before you buy.

- 0 -

LESSON 7: Transmission lines (II)

We have mentioned the two types of transmission line: the coaxial cable and the open wire feeder. The coaxial line is a concentric line, and so it is always round in appearance. It consists of a (solid or stranded) centre wire, surrounded by a sleeve of insulating material, the so-called dielectric. (See figure 10). In high-quality coax lines, the dielectric is air, and to keep the centre wire insulated from the cylindrical outer conductor, either beads of insulating material, or foamed polyethylene is used. Most coaxial lines in use by amateurs and radio listeners, however, have a solid dielectric, like teflon or polypropylene.

The insulating sleeve is surrounded by the metal outer conductor. In most inexpensive lines, this is made of a braided mesh. Around this is the final protective plastic insulation, which has no electrical function but protects the line against atmospheric influences like rain, and dirt, and light mechanical damage. Many coaxial lines can be used outdoors, and some types can even be buried in the ground.

The advantage of coaxial cable is that it does not need precautions to avoid outside influences. It can be hooked up and guided along any surface without having its electric properties changed. This makes it easy to install. A coaxial line also has some practical disadvantages: it is asymmetrical (unbalanced), and using it with a symmetrical antenna will give some signal loss. Also, it introduces more signal attenuation than the open wire feeder, which is a factor of importance when a considerable length of cable has to be applied. It is also more expensive than the open wire feeder, and its characteristic impedance is rather low: usually 50 or 75 ohms. It will be hard to find a 125 ohms coaxial line. However, the coaxial line enjoys a growing popularity, especially now that both radio receiver and television receiver manufacturers are equipping an increasing number of receivers with an unbalanced 50 or 75 ohms antenna input impedance.

The other important type of feeder line is the open wire or parallel feeder. It consists of two wires of equal diameter, which run parallel at a small distance. In the best types, the "dielectric" between them is again air, and ceramic spreaders are used to keep the wires at the predetermined distance. In most commercially available lines, the insulating material is polyethylene or a similar plastic. Figure 11 shows a type in common use.

The appearance of most commercial "twin lines" is flat, with the insulation either translucent white or a brownish black. That is why this type of cable received the nickname "ribbon". Some cheaper types have the disadvantage that the insulating material ages with time, and tends to harden in the long run. These processes change the insulating properties of the line, and thus its characteristic impedance.

A better twin line is the modern tubular line, where the two wires are imbedded in a round plastic sleeve, and foam insulation fills the hollow tube in between. Foam is almost as good as air, since it mainly consists of air bubbles, and keeps its dielectric properties much longer than the ordinary twin lead.

The open wire parallel feeder is a balanced feeder, and as such the obvious choice to operate in conjunction with balanced antennas, like the dipole and the quad. The

characteristic impedance is usually around 240 or 300 ohms, and perfectly suits the feedpoint impedance of the folded dipole.

An advantage of the parallel feeder is that it has a low loss, and can easily be home-made Home-made types usually are made up of two copper wires of 1 mm diameter, which are kept apart by home-made (plastic) insulators, as shown in figure 12. The characteristic impedance of the line can be adapted to your needs by varying the distance of the wires. This is illustrated in the table below:

Z_o (Ohms)	Centre-to-centre distance of conductors
75	1.25 x diameter
96	1.4 x diameter
150	1.9 x diameter
200	2.7 x diameter
240	4.0 x diameter
300	6.5 x diameter
350	9.5 x diameter
400	14 x diameter
450	21.5 x diameter
600	82 x diameter

(Z_o is the symbol for the characteristic impedance)

It should be kept in mind that such a transmission line must be strung taut in order to keep the conductors parallel.

The twin line feeder has some disadvantages: it can pick up local interference fields, and its symmetrical characteristics can be adversely affected by the nearness of large metal surfaces. To keep these effects to a minimum, a twin line feeder is always mounted on stand-off insulators and kept at 15 - 20 cm distance from roofs, walls, etc., while large metal objects like gutters are crossed rather than running the line parallel to it. The stand-off insulators are usually applied at 1.5 metres (5 ft) distance. If the line suffers from local interference-pickup, one way to minimize this effect is to twist it a few times to the right between two insulators, and to apply the same number of turns, but to the left, between the next standoff-insulators. This procedure is usually applied to the route of the feeder which is closest to the street, but there is no harm in twisting the line alternatively left and right between insulators all the way down.

- 0 -

LESSON 8: Antenna practice (I)

The function of the antenna is to extract as much energy as possible from the passing wavefield, and to loose as little as possible to the surroundings. In a practical sense, this means that the antenna must be situated as freestanding as possible, and that care should be taken for proper insulation. In many cases, however, compromises will have to be found, due to local circumstances and practical possibilities. This makes it hard for us to give detailed advice, and so we have to stick to generalities.

In order to prevent ohmic losses as much as possible, it is advisable to use copper wire. A diameter of 1 mm seems appropriate for shortwave reception purposes, but 0.8 mm or 1.5 mm can be used just as well, as long as the wire has a sufficient mechanical strength to withstand high winds and, in some cases, even icing.

The standard-insulator used in professional antennas is the glazed porcelain type, or the pyrex glass insulator. Because its surface is hard and smooth, dust and dirt will not easily accumulate on it, so that signal losses (especially in wet weather) are limited as much as possible. The centre insulator in dipole and quad antenna types requires

special attention, since it not only terminates the dipole, but also acts as a support for the feeder line. In order to make it suitable for both, select an insulator with a width of approx. 8 or 10 cm. The upcoming transmission line can be tied around it (and secured with insulating tape), so that the joints of feeder line and antenna are free of mechanical stress. It is almost essential to solder these joints, but if this is impossible, keep in mind to make a joint which guarantees an excellent electrical contact between the wires and which is secured against corrosion (rust) by paint or some other non-conducting protective.

Coupling a twin line feeder to a balanced antenna will obviously give no problems: each antenna limb is connected to one of the two wires of the feeder. When coaxial lines are used, the centre wire and the screening braid are each connected to one of the antenna limbs. The unbalanced-balanced transfer will give some signal loss, which could be corrected with a so-called balun, or balance-unbalance transformer, which consists of two pieces of insulated wire, wound around a toroidal (ring-shaped) ferrite core, as indicated in figure 13. This balun, which is rather popular among radio amateurs, also had the advantage of a 1-to-4 impedance transformation, so that a 75 coaxial line can now be decently hooked up to 300 ohm folded dipole.

Not all antennas are symmetrical. An example is the ground plane antenna, which has a feedpoint impedance of around 36 ohms when the ground plane is perpendicular to the rod. Such an antenna is always combined with a coaxial cable, usually the 50 ohm type. In order to arrive at a better match between feeder and antenna, the radials are usually bent downwards until they form angles of about 135° with the rod (45° with the horizontal plane). This increases the feedpoint impedance of the ground plane antenna to about 50 ohms, and it will often be a suitable solution for houses with slanting roofs. The radials can then be strung parallel to the roof.

The connections between antenna and feeder are simple: the centre conductor of the coax line is hooked up to the vertical rod, and the screening braid to the centre of the four radials. This centre can be a small copper plate, or a copper ring, situated slightly below the bottom end of the rod (and insulated from it).

Most resonant antennas are 5% shorter than the electrical length. A half-wave antenna thus has a practical length of 0.475 λ between the terminal insulators, and a quarter-wave type has a practical length of 0.238 λ. The limbs are of the same length, to maintain the balance. The 5% shortening applies to antennas which are thin in proportion to their length, like wires or thin rods. For cage dipoles, biconical dipoles (fig. 14) or flagpole type antennas, the shortening factor increases according to the table below.

Dipole ratio length / diameter	Shortening factor
100	0.92
200	0.93
400	0.94
1,000	0.95
2,000	0.96

- 0 -

LESSON 9: Antenna practice (II)

So far, we have occasionally given you details of antenna and feedline impedances, and we have mentioned the fact that a proper matching is necessary in order to prevent excessive signal loss in the transmission line. Some practical examples of proper matching are: a 50 ohm coaxial line to a ground plane antenna or a half-wave loop, a 75 ohm coaxial line to a single half-wave dipole or a quad antenna, and a 300 ohm twin line to a folded dipole.

If the antenna impedance deviates from one of these "standard" values, you can achieve proper matching by either adapting the feedline impedance to the antenna feedpoint impedance, or by adapting the antenna feedpoint impedance to that of a standard line. The home-made twin line (discussed in lesson 7) applies to the first case. Changing the antenna feedpoint impedance is next. The folded dipole is, in this respect, a versatile antenna. Its feedpoint impedance can be changed in two ways: by varying the diameter of the upper (uninterrupted) conductor with respect to the lower (interrupted) one, or by adding a second uninterrupted conductor. See figure 15.

We have seen that the addition of one conductor of similar diameter changes the feedpoint impedance of the single dipole with a factor 4 to about 300 ohms. If we apply a second conductor, the impedance rises to 9 x 73 = 657 ohms, a value which is attractive to many older domestic receivers, especially when it is combined with a 600 ohms parallel feeder line (home-made). It is possible to increase the feedpoint impedance of the dipole even further by adding a third parallel conductor, but this becomes rather impractical in view of possible changes in the characteristics of the system with varying weather conditions. Any feedpoint impedance between 300 and 600 ohms can be realized by increasing the diameter of the upper conductor of the folded dipole with respect to the lower one, as shown in the following table:

Ratio $\frac{d_{upper}}{d_{lower}}$	Centre-to-centre distance of conductors	Feedpoint impedance
2	5	390
2	10	360
3	5	450
3	10	410
4	5	500
4	10	440
5	5	530
5	10	470

The home-made twin line offers you the possibility of a perfect match. The difficulty, of course, is that the antenna input impedances of many receivers are unknown (but known to the manufacturer).

Most semi-professional and professional receivers now have a 50 ohms (unbalanced) input, but most domestic types and portables have a balanced input, which is much higher. 600 ohms is a regularly heard value, but there is often no certainty and only some experiments with different types of transmission line may give you the answer.

Older receivers usually have a rather loose coupling between the antenna coil and the RF coil of the first receiver stage. This would indicate that the choice of antenna and feedline impedances is not too critical, and that the emphasis in antenna construction lies in the proper matching between antenna and feederline, and in the antenna gain and directive properties. The feeder line is hooked up to the antenna and the earth (ground) terminals of the receiver. If a coaxial line is used as a feeder, the screening braid is always connected to the earth terminal.

If you start thinking about a new antenna, in accordance with the data described in this course, the best way to start is to establish (if possible) the antenna input impedance of the set, and to adapt the impedance of feeder line and antenna accordingly.

The toroidal balun and the home-made feeder give you freedom to arrive at proper matching without having to use measuring instruments. Other matching methods and baluns do exist, and are used. Many of them can be found in books for the radio amateur under such names as: delta-match, T-match, and stub match. These matching systems do give the required

impedance transformation, but some lead to signal loss because they are part of the radiation system. Also, the use of measuring instruments is needed to arrive at optimal results.

There is one other matching system which can easily be home-made and does not require the use of measuring instruments. It is called the Q-match, and it consists of two parallel wires or rods, each ¼ wave (multiplied by the velocity factor) long, and connected between the antenna and the feeder line. This quarter-wave piece of feedline (see figure 16) has an impedance which is equal to the square root of the product of the antenna and feedline impedances.

$$Z_o = \sqrt{Z_a \times Z_f}$$

If the feedline impedance were 50 ohms, and the antenna feedpoint impedance 240 ohms, the impedance of the Q-match has to be $\sqrt{50 \times 240}$ = 110 ohms. Details for a feeder line with this characteristic impedance can be found in the table for home-made twin line (centre-to-centre distance of the wires is approximately 1.5 x the wire diameter.

So the Q-match is a balanced matching system, which can be used in all necessary circumstances. The toroidal balun is a combination of a 1 to 4 matching unit, plus a balun. See figure 13 for details.

Matching and balancing are not always necessary for receiving purposes. Balancing is considered of little effect below frequencies of 20 MHz (15 metres), and matching becomes desirable only if the impedances deviate 30% or more from the standard.

- 0 -

LESSON 10: The vertical antenna

The quarter-wave vertical antenna is available in various shapes. One of these is the vertical tower placed on an insulator, with radials buried in the ground. The other is the ground plane version, where the radial system is replaced by an "artificial" ground plane, consisting of four radials, each ¼ wave long. The number "four" is just a practical value, there would be no objection whatsoever if 6 or 8 radials were applied, as long as they are evenly distributed.

In shortwave practice, both versions of this vertical antenna are applied. A simple grounding rod, or a copper strip, will sometimes replace the radial ground system of the first type mentioned. The ground based vertical can be an aluminium or copper pole, kept upright by a wooden support which is partly buried in the ground, and with two stand-off insulators to keep the pole vertical. The grounding rod, also made of copper, is driven into the ground as deep as possible (at least 4 ft) at a place just underneath or slightly beside the vertical. We now have the two points to which the coaxial line can be connected (the screening braid of the cable to the grounding rod).

In the case of the ground plane antenna, the situation is similar; the radials form a geosymmetrical point (a small copper plate, or ring in the centre), which acts as a feedpoint connection for the coaxial cable. Which of the two antennas has preference, depends on the local situation. The ground plane antenna is usually situated over a roof, or is erected on top of a pole, with the radials pointing downwards. Such a position gives the antenna a considerable receiving ability. The "grounded" vertical is near the ground, and is only recommended in rural areas, where it can still be positioned "free-standing".

To extend the versatility of the vertical antenna, we can change its "electrical length" to keep it resonant at various wavebands, by adding top capacity, or base loading, or by applying a shortening capacitor. In practice, we apply a matching network at the base of the vertical rod, as illustrated in figure 17. It consists of a loading coil, which can be adapted to the characteristic impedance of the feedline by tapping it at various lower turns, as indicated.

If a coil with an ample number of turns is available, we can arrive at the proper matching for each band by short-circuiting a number of turns. To prevent shifting or uncoiling, the ends of the winding can be secured by leading the wire through twin holes drilled near each end of the core.

The loading coil has the best quality when it is wound around a 2 to 2½ inch (5 to 7 cm) plastic tube. The tube should be long enough to hold 15 turns of enamelled copper wire of at least 1 mm diameter. The turns should be separated by spaces which equal the wire diameter. In practice, you can wind the coil by applying two wires simultaneously, and removing one of the windings afterwards. The correct spacing will then automatically result.

Tapping is done by removing the enamel insulation of the wire at every second winding from the top. With a 5-way switch for short-circuiting, you can cover up to 10 windings. At the cleaned spots of the wire, you solder (thin) wires which lead to the contacts of the switch. At the bottom end of the coil, you can apply another 5-way switch, which will enable you to tap the coil at every single winding (up to five).

The matching unit can be housed in a small metal box, which is then connected between the antenna and the ground, as explained earlier. One last tip: the top of the rod must either be rounded, or end in a small ball or disc. This is to limit crackling, caused by static discharges which can occur at sharp points.

If the vertical antenna is made adjustable to various wavebands, the radials should measure ¼ of the longest wavelength to which the antenna can be tuned. If you want to learn more about the whip antenna, and the way to tune it, we suggest that you acquire one of the books on this subject which are avaialble for radio amateurs. Well known is the ARRL Antenna handbook (American Radio Relay League, Newington, Conn., USA).

- 0 -

LESSON 11: The parasitic beam antenna

The dipole antenna is the principal unit in a number of antenna systems: combinations of dipoles, or of dipoles and other to enhance certain properties, like gain, or directivity, or front-to-back ratio.

One of the simplest of these is the parasitic array, or Yagi-antenna. It consists of a half-wave dipole, with parasitic elements of specific lengths running parallel to the dipole at prescribed distances. This is illustrated in fig. 18 for a so-called three-element beam antenna. The element running at the rear of the antenna (as seen from the transmitter)is 5 percent longer than the dipole (and thus equal to ¼ wave-length, and called the reflector. It is just a simple wire, or rod, well insulated from its surroundings and not connected to any other conductor. A similar element placed in front of the dipole, but 5% shorter than the actual dipole, is called the director.

Both the reflector and the director serve to narrow the horizontal beam-width of the dipole, and to improve its gain. The spacing of the parasitic elements with respect to the dipole determinestheir overall effect. We will explain this further on.

The height of the array above the ground is also to be considered, because it determines the elevation angle of the main antenna lobe. Particulars about this subject are given in lesson 3.

How does such a system operate? A simple explanation is hard to give but basically the parasitic elements increase the amount of signal captivated by the dipole, by acting as resonant elements which receive and (because there is no load connected) reradiate a signal, which is then picked up by the dipole. The spacing between the dipole and the parasitic elements is therefore crucial. For a theoretical value of ¼ wave-length, the return signal from the reflector arrives at the dipole in step (in phase) with the incoming signal, thus boosting its efficiency. Usually, the reflector element is made resonant to the low-frequency side of the dipole resonance (so, it is slightly longer than the dipole) while the director is adjusted to its high-frequency side. Sometimes,

the "electrical length" of a parasitic element is reached differently, by putting a coil or a capacitor at its centre.

The two-element beam (dipole and reflector) has a horizontal diagram as shown in fig. 19. It is basically unidirectional. The gain of the array is highest when the spacing between reflector and dipole is chosen between 0.12 λ and 0.22 λ . It is then about 5 dB over that of an isotropic source. The feedpoint impedance varies for different spacings, and so does the bandwidth of the system. The smaller the spacing, the lower these become. If a single dipole is the driven element of the array (nominal impedance 73 ohms), the radiation resistance becomes 20 ohms for a 0.15 λ spacing, 40 ohms for a 0.2 λ spacing, and 50 ohms for a 0.22 λ spacing. In order to avoid excessive signal loss due to reflections on the transmission line, a dipole-reflector spacing of 0.22 λ is usually employed. If a folded dipole (300 ohms) is used as the driven element of the array, the radiation resistance of the array will also multiply by four, and become respectively 80, 160 and 200 ohms for the various spacings mentioned.

The introduction of a director further improves the gain, narrows the horizontal beam-width (see fig. 20) and also reduces the radiation resistance of this so-called three-element beam. A director length of 0.45 λ and a spacing of between 0.16 λ and 0.21 λ gives a gain which now totals about 7 dB above an isotropic source. The radiation resistance of the array drops to a highest value of 40 ohms at 0.2 λ spacing, and is about 30 ohms at 0.15 λ spacing (single dipole system). If a folded dipole is used as the driven element, these values are multiplied by four. The data given are important with respect to the choice of the type of feeder line and the driven element, so as to arrive at the closest possible match for the receiver.

The practical parasitic beam antenna can be made of copper wire, if the antenna is used mostly in a fixed direction. A rotatable beam array is usually made of aluminium tubing. Because of the harmonic relationships of many amateurbands, multi-band beams are among the most popular antennas among advanced radio amateurs.

In many countries, these beams are commercially available, and are made rotatable to enable the operator to "work" different parts of the world. Rotatable beams employ a central rod (metal or wood) to support the antenna and the parasitic elements at their centres. This is called the boom. The dipole itself is kept well-insulated from the boom, but the reflector and the director can be fixed directly on it, as long as the connection is exactly in the centre of the parasitic elements.

The practical way to construct wire beams is to terminate all elements with (similar) insulators, and to support them from two (bamboo or fibreglass) spreaders, as indicated in figure 21. More particulars on beam antennas, including types with "active" rather than "parasitic" elements, can be found in radio amateur literature. A book which deals with the topic of this lesson only is the Beam Antenna Handbook by William I Orr (Radio Publications,Inc. Wilton, Conn. 06897, USA), which sells for about six dollars and supplies 200 pages of information for it.

- 0 -

LESSON 12: The quad antenna

The quad antenna is an array consisting of two vertical loops (usually full wave), spaced at a fraction of one wavelength. The loops are supported by a central boom (which points in the direction of maximum sensitivity for the antenna), on which two cross-shaped frameworks are mounted which hold the corners of the loops. The crosses can be made of light tubing, with insulating rods inserted at each end to attach the wire to. Bamboo is also widely used. U-bolts can be used to fix the rods to the centre plates, which are placed at each end of the support boom. The length of this boom is then equal to the spacing of the antenna elements. Figure 22 gives an impression of a two-element quad antenna.

Like the beam antenna, the quad is basically a one-band antenna. However, quads for several bands may use the same basic support construction, without hampering each other's

operation.

A two-element quad antenna has a horizontal beamwidth of about 60°, a front-to-back ratio of 10 dB, a bandwidth of about 6%, and a maximum gain of about 7 dB. The spacing of the elements is usually kept at 0.15 λ , but is not critical as long as it is kept between 0.12 λ and 0.17 λ. The radiation resistance, however, changes with the spacing of the elements as follows:

0.1 λ	60 Ω (ohms)
0.12 λ	70 Ω ← maximum gain
0.15 λ	85 Ω
0.18 λ	100 Ω
0.2 λ	110 Ω

The optimum height of the centre of the antenna (the boom) above the ground is about ½ λ ; the elevation angle is then 26°. At 3/8 λ , it is about 32°, and at ¼ λ it becomes 40°.

The driven element of the quad is the full wave loop (fig. 9). The optimum side length is slightly longer than a quarter wave: 0.257 λ . The reflector can either be a completely closed loop, or it can be made like the driven element, the terminals being terminated by a (tuning) stub. Since this would require the use of measuring instruments, we will stick to the completely closed loop. It is advised to make each limb 3% longer than that of the driven element; this results in a limb length of 0.265 λ .

The two-element quad can be extended to become a three-element quad, by adding a director loop in front of the driven element (and in a parallel plane) at a distance of 0.15 λ . This array has a gain of about 9 dBi* and a horizontal beamwidth of about 45° at the design frequency.

The director loop has a leg length which is 3% shorter than that of the driven element. The fair distance of 0.15 λ will limit the reduction of the feedpoint impedance, so that the three-element quad can still be fed by a 75 ohm coaxial cable or 75 ohm twin line (the latter is a balanced line, and recommended in combination with this type of antenna). This rather narrow angle will make a rotatable construction for the antenna almost inevitable; a rather expensive extra which may be a drawback for you to acquire this antenna.

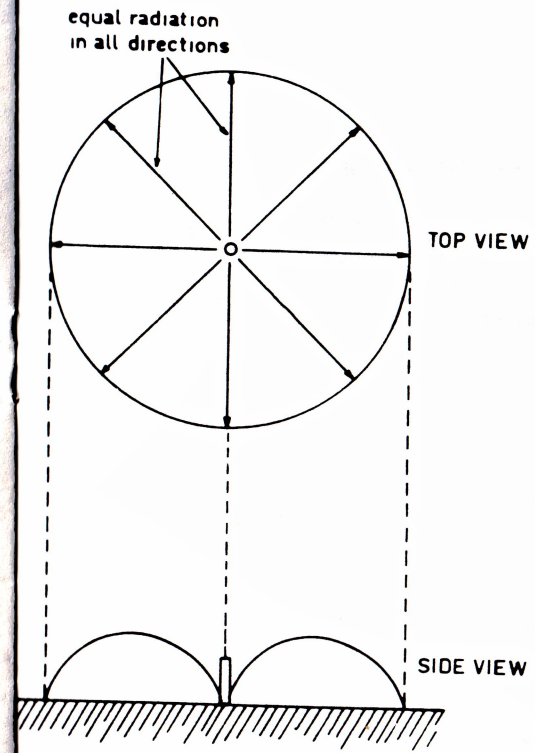
Another, and probably more appreciated, variation of the two-element quad is its multi-band-version. Usually, this is achieved by constructing concentric loops and selecting an element spacing which is a compromise (e.g., 0.12 λ for the lowest frequency band and 0.18 λ for the highest one). A good practical example for a broadcast tri-bander is a concentric two-element quad for the 13, 16 and 19 metre bands. The feedpoints of the three driven elements are interconnected by short, vertical conductors, and the middle element is hooked up to the feedline. In fact, the three loops are now connected in parallel. We recommend that such a three-band affair should not be assembled right-away, but that the quad for the longest wavelength is made first. If you prepare the support construction beforehand, more loops can be added on the same frames later on. Once you have a single band quad, try it out for a convenient period before you make the decision to improve or extend the antenna.

The quad antenna is the last antenna type dealt with in this antenna course. It is also one of the most popular antenna types of the advanced DXer, as it is relatively easy to build with inexpensive parts, which are locally available. It requires a limited space, and can be made so light-weight that no-one will have trouble erecting it. More detailed information on quads, and more specific information on antennas, can be found in books on the subject, especially in radio-amateur literature.

* dBi is decibel value based on an isotropic source

The aim of this course has been to increase your insight in the matter of antennas in general and of shortwave types in particular. We hope that you have found it useful, and that it has stimulated your interest enough to continue reading and learning about antennas.

Jim Vastenhoud
for
RADIO NEDERLAND



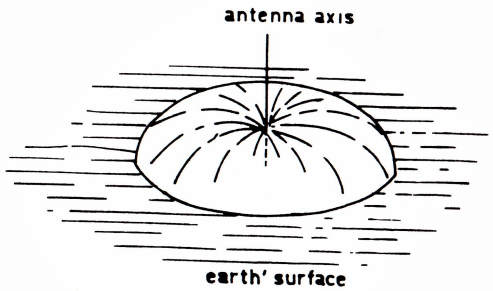


fig. 1

The top view (horizontal pattern) shows equal radiation in all directions, as characteristic for an omnidirectional antenna. The side view (vertical pattern) shows that the upward radiation is zero, the oblique radiation varies with the angle of elevation, and the level radiation is greatest.

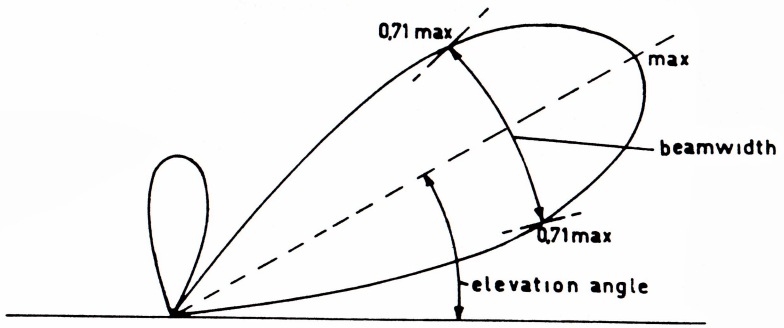


fig. 2

The diagram of fig. 2 shows the directivity of an antenna in the vertical plane. From the antenna position (where the diagram emerges), the distances to the various points that form the radiation pattern, show the relative amount of radiation in that direction. The maximum radiation occurs along the dotted line.

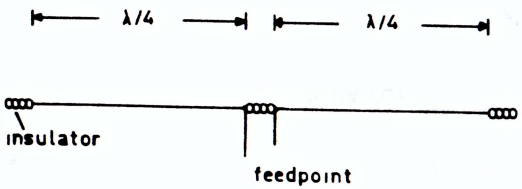


fig. 3

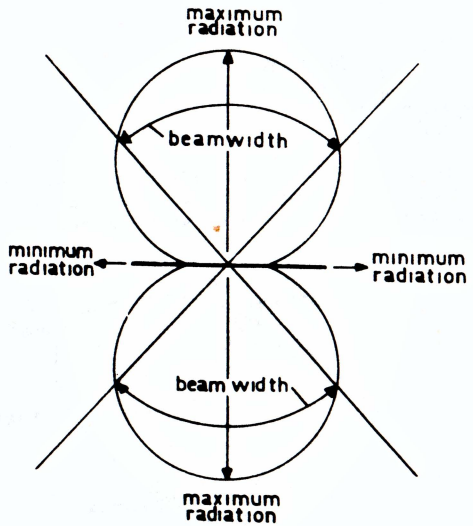


fig. 4

81 SWAC

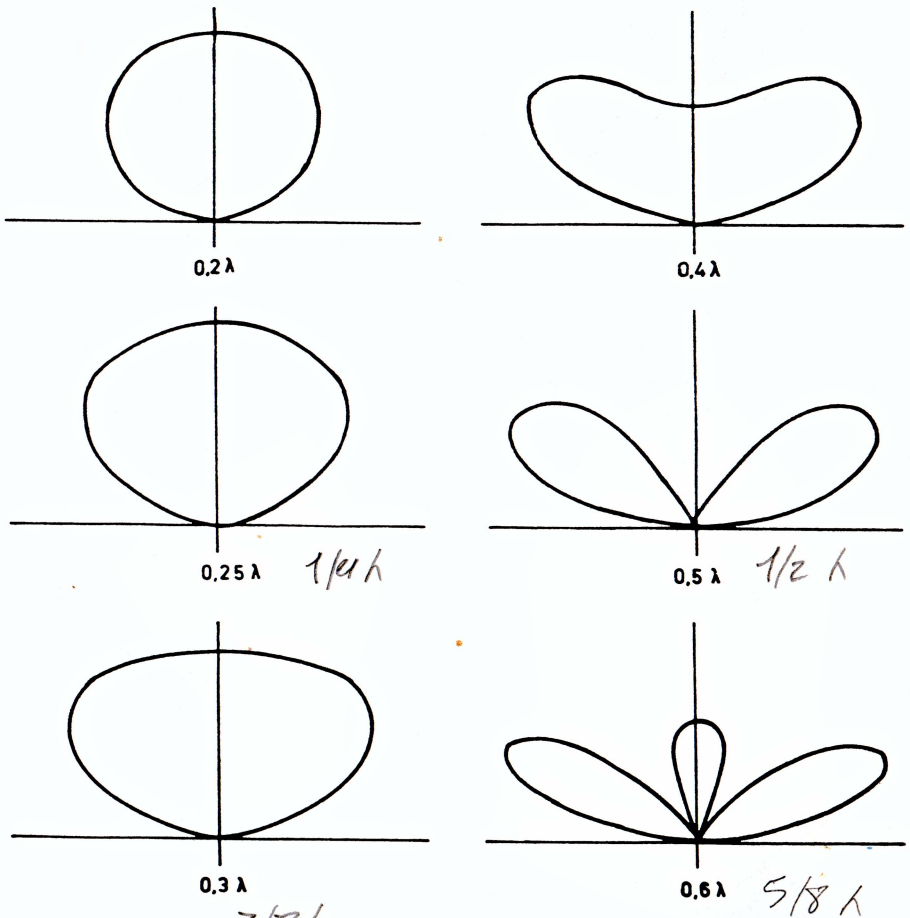


fig. 5

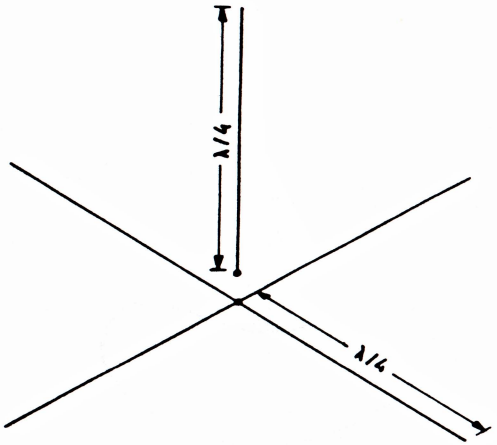


fig. 6

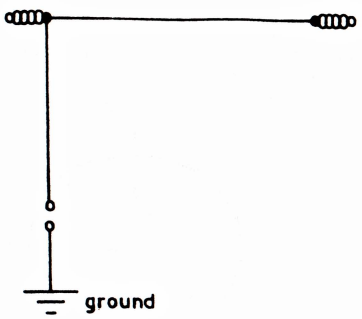


fig. 7

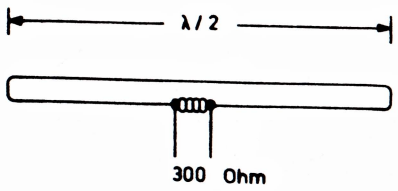


fig. 8

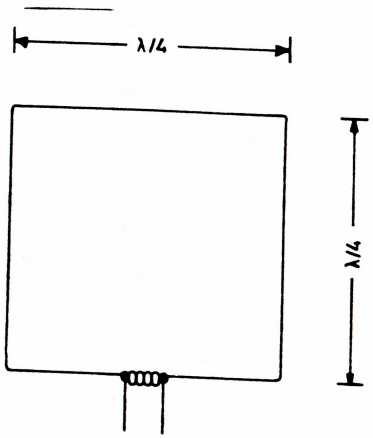


fig. 9

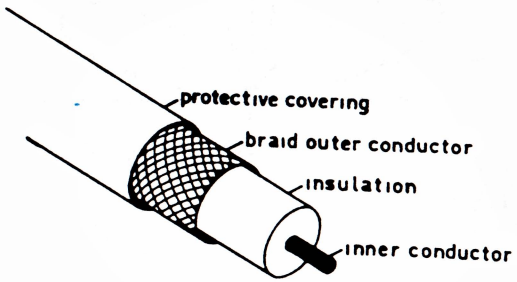


fig. 10

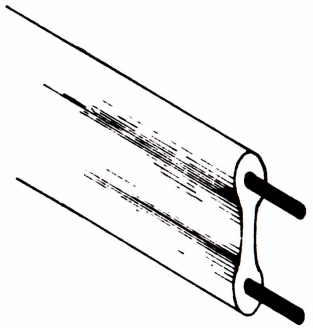


fig. 11

81 SWAC

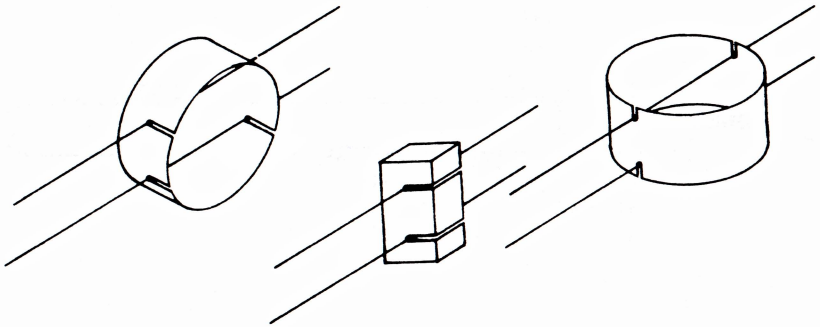


fig. 12

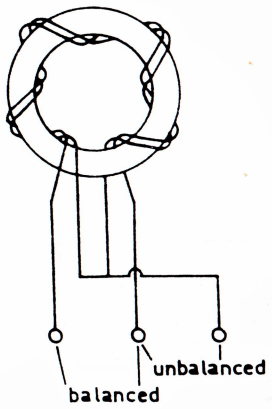


fig. 13

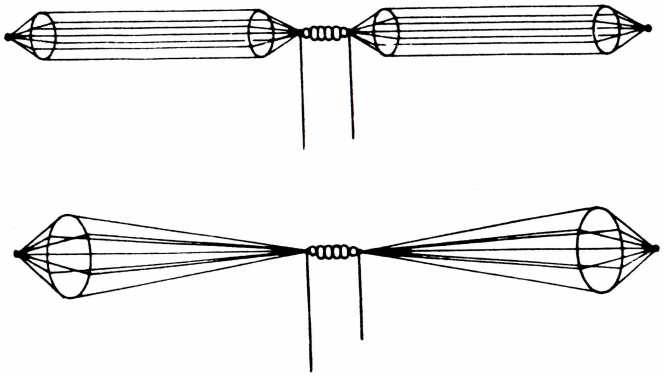


fig. 14

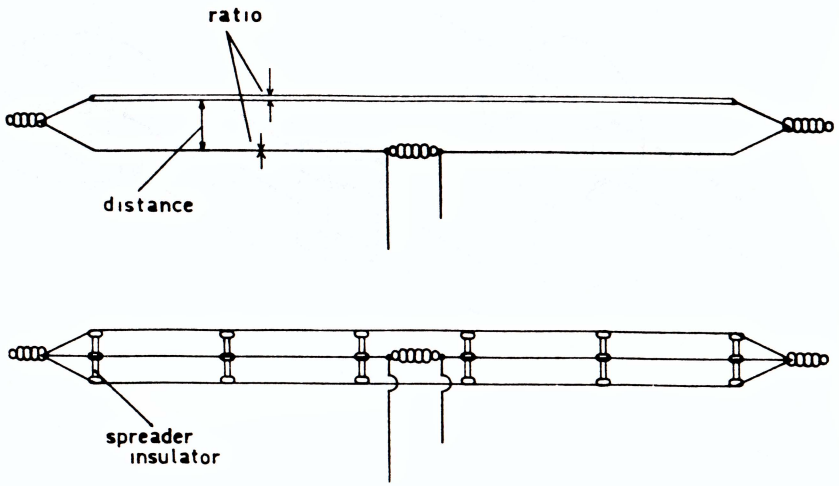


fig 15

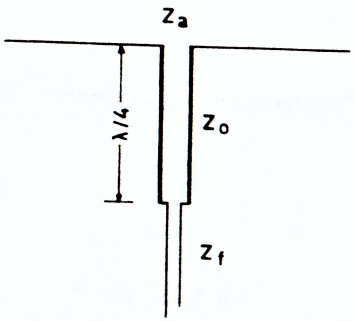


fig. 16

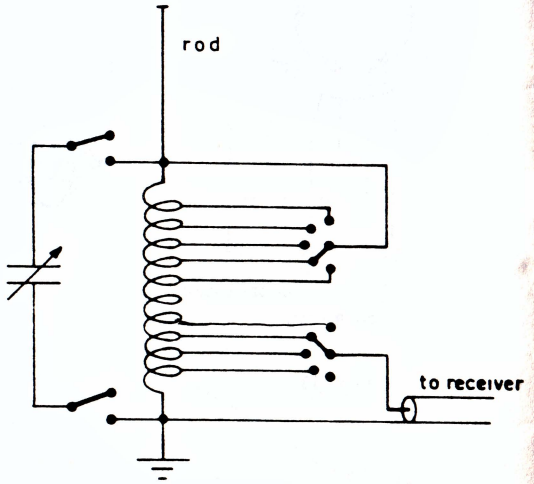


fig 17

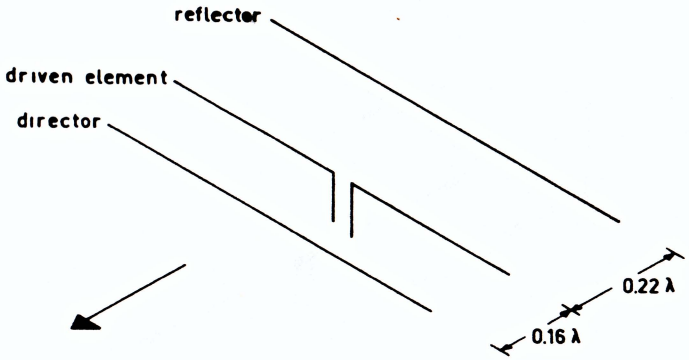


fig 18

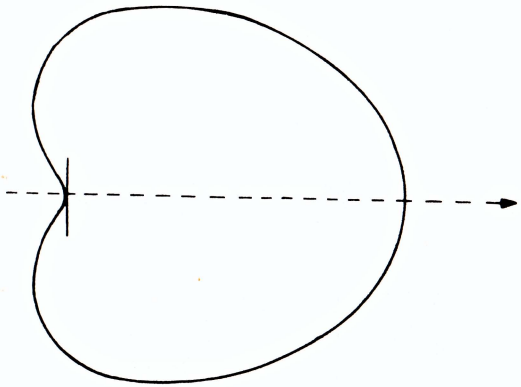


fig. 19

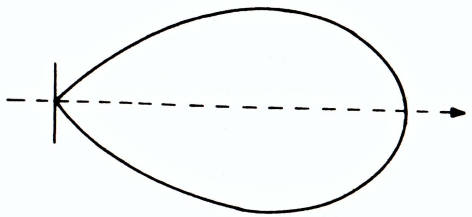


fig. 20